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**Student Program in Satellite Oceanography
(NAGW-1123)**

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Final Report

1. Introduction

This two-year project had two goals: 1) to provide support and training for oceanography students engaged in satellite data analysis and oceanographic modeling; and 2) to provide computer equipment that would facilitate satellite oceanography, numerical modeling and the assimilation of satellite data into numerical models in the College of Oceanography at OSU. To accomplish these goals, NASA provided support for two graduate students during the first year and three students during the second year. NASA also provided funds for the purchase of computer equipment in each of the two years.

2. Students Supported

Part of the student support was intended for "exchange" students who were enrolled in other PhD programs and who would attend OSU for a year and receive a MS degree in physical oceanography. To accomodate such students, a special MS program in physical oceanography was designed, which required no thesis. The hope was to expose top students in engineering and mathematics to satellite oceanography and modeling and to gain "recruits" to oceanography in this way. The rest of the student support was intended for regular MS and PhD students, who were engaged in remote sensing and/or modeling research, and who needed support for a period of 1-2 years.

The Aerospace Engineering group at the University of Colorado (CU) was chosen as the target institution for the exchange program, based on previous faculty contacts with that group. Two CU students applied the first year and one was accepted (Gregg Jacobs); he attended OSU for a year, receiving an MS as described above. The other half of the student funding supported Alberto Mestas-Nunez, a PhD student engaged in the analysis of Seasat scatterometer data, under the guidance of Dudley Chelton. In a variation on the exchange student idea, an OSU graduate student (Donna Witter) attended CU for a year, benefitting from their aerospace and mathematics courses. She was supported by CU during her stay.

There were no applicants from CU in the second year and the support was used for Alberto Mestas-Nunez and Donna Witter, after her return from CU. The rest of the graduate student funding was used for partial support for two students, Robin Tokmakian and Julie McClean-Padman. All of these students were involved in the analysis of various satellite data sets and have been productive, as seen in the list of presentations and papers in Appendix 1. Donna Witter and Alberto Mestas-Nunez are presently enrolled at OSU

in PhD programs. Gregg Jacobs is enrolled at CU. Robin Tokmakian has finished an MS degree and is employed in remote sensing work in England. Julie McClean-Padman transferred to a PhD program at Old Dominion University, where she is analyzing some of the results of the WOCE "community" model runs.

3. Course Development

Two courses that had existed before this program became an important part of the training in satellite oceanography, both taught initially by Dudley Chelton. A course in Satellite Oceanography covers the theory of remote sensing and applied aspects of the use of satellite data. Some of the teaching load for this course has been shared, first by Ted Strub and later by Mark Abbott. A course in Oceanographic Time Series Analysis covers the methods of analyzing large data sets, such as obtained from satellites. Part of the teaching load for this course has also been shared by Ted Strub. Two additional courses were developed to cover the numerical modeling aspect of the desired training. A course in Numerical Modeling of Ocean Circulation was developed by Robert Miller. A course in Inverse Modeling and Data Assimilation was developed by Andrew Bennett.

By the end of this year, all of these course will have been taught at least twice. They provide the students with "hands-on" experience in modeling, data assimilation and statistical analysis of data and model output. They also make extensive use of the computer equipment described below. With these courses and the regular sequence of course on theoretical GFDL and descriptive oceanography, we feel that the students are offered a strong program of training in modern physical oceanographic theory and practice, including the modeling and satellite data analysis that has become a vital part of the field.

4. Computing Equipment

In the original proposal, four types of computing equipment were identified: 1) a relatively powerful local research computing capability; 2) a computer facility for use in the modeling and data analysis courses that were described in the previous section; 3) a high speed link between the College of Oceanography and supercomputer centers; and 4) image processing hardware and software.

During the first year, the equipment purchased included a SUN 3/280 server with 16 MB memory, floating point accelerator, 1.1 GB of disk, and a 1/2 inch tape drive; it also included two SUN 3/60 workstations (one color, one monochrome) primarily for student use, a laser printer and a color (paint-jet) printer. The 3/280 was one of two such servers purchased at the time (the other was purchased with College funds) to form the backbone of the College of Oceanography computer system. This server satisfies the need for the computing carried out during the courses and for individual research projects that are not too compute intensive. The other SUN server performs disk service and supplies the high speed link to the campus ethernet, which in turn connects us to NCAR and NSFNET, allowing access to supercomputer facilities for the more compute

intensive needs. The workstations provide additional cpu power and some basic image display capabilities; however, most of the image processing in the first year of the project still had to be done on the microVAX system maintained with research funding by Dudley Chelton and Ted Strub.

During the second year, the equipment purchased included 1.8 GB of hard-disk for the microVAX system used by Drs. Chelton, Strub, Richman and their programmers, post-docs and students. This was necessary to accomodate the growing use of this system to analyze a number of large satellite data sets (altimeter, AVHRR, CZCS, scatterometer, SMMR). The rest of the funding was used to purchase an HP 370 color workstation, with 8 MB memory, floating point accelerator, 900 MB of disk, a 1/2 inch tape drive and a printer/plotter. This workstation was chosen because Mark Abbott was willing to donate a Metheus frame buffer and color monitor, giving the workstation the capability of running the Global Imaging image-processing software (primarily for AVHRR and CZCS analysis). Mark Abbott also donated the license for the Global Imaging software and an optical disk drive. This system provides the image-processing capability identified as the fourth equipment need above. It is used, mostly by students, for analysis of the West Coast Time Series of CZCS and AVHRR data and for processing new AVHRR images.

These machines are used by students and faculty for individual research, in the courses described above, and more recently in other courses, such as the Introduction to Physical Oceanography and the Analysis of Geologic Data Bases. During the courses, the average Unix load number on the 3/280 server is 12-18, compared to a normal load of 2-3. In Appendix 2 we list projects, papers and presentations which made use of this equipment. Present plans call for upgrading the SUN 3/280 servers in the near future to give them the power needed to manage the growing load on the system due to both research and teaching, especially looking ahead to the NASA-funded EOS work planned by Mark Abbott's interdisciplinary team.

Thus, the original goals of the proposal have been met and exceeded. Five students were supported, four of whom are active in satellite oceanography, while the other is engaged in a modeling study. Classes are taught in satellite oceanography and the statistical techniques of analyzing large data sets, as well as in numerical modeling of ocean circulation, inverse modeling and data assimilation. A large number of faculty and students have been enabled to engage in remote sensing and modeling research, which would have been much more difficult (or impossible) without this equipment.

Appendix 1
Presentations and Papers by Students Supported by This Grant

Gregg Jacobs

Jacobs, G.A., R.R. Leben and G.H. Born: Visualization of periodic flows in the north Atlantic and Gulf of Mexico using GEOSAT altimeter data, presented at the Fall 1989 AGU Conference.

Emery, W.J. and G.A. Jacobs: Time and length scales of sea surface features over Fieberling Seamount; Analysis of satellite altimetry and infrared radiometry, presented at the Spring 1990 AGU Conference.

Jacobs, G.A., W.J. Emery, and G.H. Born: Least squares fitting of barotropic and first mode baroclinic Rossby waves to GEOSAT data over the Pacific ocean, presented at the Fall 1990 AGU Conference.

Jacobs, G.A. and R.R. Leben: Loop current eddy shedding using GEOSAT altimeter data, Geophys Res. Letters, vol 17, 2385-2388, 1990.

Donna Witter

Witter, D.L., D.B. Chelton, M.G. Schlax and J.G. Richman: Satellite altimeter observations of the surface circulation in the Southern Ocean, presented at the Inaugural Meeting of The Oceanography Society, 1989.

Witter, D.L., and D.B. Chelton: Alternative parameterizations of the sea-state bias in Geosat altimeter height measurements, presented at the AGU Ocean Sciences Meeting, 1990.

Witter, D.L., and D.B. Chelton: A method for developing an altimeter wind speed algorithm, with application to Geosat, J. Geophys. Res. (in press), 1991.

Witter, D.L., and D.B. Chelton: An apparent wave height dependence in the sea state bias in Geosat altimeter range measurements, J. Geophys. Res. (in press) 1991.

Alberto Mestas-Nunez

Mestas-Nunez, A.M, and D.B. Chelton, An investigation of Sverdrup dynamics in the Southern Ocean from the Seasat altimeter and scatterometer, presented at the Inaugural Meeting of The Oceanography Society, 1989.

Mestas-Nunez, A.M., and D.B. Chelton, An investigation of Sverdrup dynamics on seasonal times scales in the southern ocean, presented at the AGU Ocean Sciences Meeting, 1990.

Mestas-Nunez, A.M., D.B. Chelton, and D.L. Witter, Geosat altimeter observations of the surface circulation of the Southern Ocean, presented at the Conference on Water Masses and Circulation of the Southern Ocean, Brest, France, 1990.

Chelton D.B., A.M. Mestas-Nunez and M.H. Freilich: Global wind stress and Sverdrup circulation from the Seasat scatterometer, J. Phys. Oceanogr., vol 20, 1175-1205, 1990.

A.M. Mestas-Nunez, D.B. Chelton and R.A. deSzoeko: An investigation of time-dependent Sverdrup dynamics in the Southern Ocean from the Seasat scatterometer and altimeter, J Phys. Oceanogr., (submitted) 1991.

Robin Tokmakian

Tokmakian, R., P.T. Strub, and J. McClean-Padman, Computing coastal velocities from CZCS and AVHRR satellite imagery, presented at the Fall 1988 AGU Conference.

Tokmakian, R., Estimating surface velocity from sequential satellite images, presented at the Eastern Pacific Oceanographic Conference, 1989.

Tokmakian, R., Sea Surface Velocity Determination Using Satellite Imagery: Validation and an Application, M.S. Thesis, College of Oceanography, OSU, Corvallis, OR., 1989.

Tokmakian, R., P.T. Strub, and J. McClean-Padman, Evaluation of the maximum correlation method of estimating sea surface velocities from sequential satellite images, J. Atmos. Oceanogr. Tech., vol 7, 852-865, 1990.

Tokmakian, R.T., and T.H. Guymer, Using land regions for the absolute calibration of a satellite altimeter's sigma naught parameter, presented at the Fall 1990 AGU Conference.

Julie McClean-Padman

McClean-Padman, J., P.T. Strub, and R. Tokmakian, Translational and rotational motion objectively calculated from sequential infrared satellite images, presented at the Fall 1988 AGU Conference

Appendix 2
Papers, Presentations and Projects Using the NASA Equipment

Students

Hernan Garcia

Garcia, H.E., Caribbean Sea marine research data inventory and the feasibility of establishing a coastal and marine data and information center in Venezuela, M.S. Thesis, College of Oceanography, OSU, Corvallis, OR., 1988.

Garcia, H.E., and L.I. Gordon, Principal component analysis of nutrients and hydrography in the Caribbean and tropical Atlantic Ocean, presented at the AGU Ocean Sciences Meeting, 1990.

Garcia, H.E., and L.I. Gordon, Large-scale mixing and regeneration of nutrients in the deep Atlantic Ocean, presented at the Fall 1990 AGU Conference.

Gordon, L.I., J.C. Jennings, Jr., and H.E. Garcia, Winter Weddell Gyre study, 1989: Nutrient, oxygen and biomass chemistry, presented at the Second Meeting of The Oceanographic Society, 1991.

Hongyan Li

Li, H., and J.G. Richman, The effect of nonzonal isopycnal outcrops on the ventilation of the thermocline, J. Phys. Oceanogr., (submitted), 1991.

Shusheng Luan

Luan, S., C.A. Paulson, and P.T. Strub, The long-term budgets of momentum and heat in the upper equatorial Pacific Ocean, presented at the TOGA Scientific Conference, 1990.

Luan, S., C.A. Paulson, and P.T. Strub, Diurnal variation of mixing in the upper equatorial Pacific ocean, presented at the Fall 1990 AGU Conference.

These presentations are in the process of being converted to manuscripts and the modeling of the equatorial Pacific ocean is continuing.

Rodrigo Nunez

Nunez, R.H., Prediction of Tidal Propagation and Circulation in Chilean Inland Seas Using a Frequency Domain Model, M.S. Project, College of Oceanography, OSU, Corvallis, OR., 1990.

Joe Ortiz

Ongoing analysis of AVHRR and CZCS imagery in relation to sediment trap data. Supported by a NASA Graduate Student Research Program fellowship, under the direction of Mark Abbott.

Cindy Paden

Paden, C.A., M.R. Abbott, and C.D. Winant, Tidal mixing in the Gulf of California: Observations of SST variability and surface heat fluxes using satellite infrared data, AGU Ocean Sciences Meeting, 1990.

Paden, C.A., M.R. Abbott, and C.D. Winant, Tidal and atmospheric forcing of the upper ocean in the Gulf of California, J. Geophys. Res., (accepted), 1991.

Steven Pierce

Pierce, S.D., J.S. Allen, and L.J. Walstad, Dynamics of the coastal transition zone jet: Part I, linear stability analysis, J. Geophys. Res., (accepted) 1991.

Hongbo Qi

Qi, H., and R. deSzoeko: The structure of storm-induced near-inertial internal waves, presented at the Fall 1990 AGU Conference.

Thomas Strand

Ongoing use of a barotropic model of the North Pacific Ocean to look at the inverse barometer effect on altimeter signals and to model the large-scale circulation. Supported by a NASA Graduate Student Research Program Fellowship, under the direction of Jim Richman.

Faculty and Staff

Dudley Chelton

Chelton, D.B., Satellite altimeter measurements of sea level variability in the Southern Ocean, presented at the Oceans-89 Conference, 1989.

Chelton, D.B., Satellite altimeter observations of wind forced circulation in the Southern Ocean, presented at Goddard Space Flight Center, Oceans and Ice Branch Seminar, 1989.

Chelton, D.B., Global wind stress and Sverdrup circulation from the Seasat scatterometer, presented at the NCAR Oceanography Seminar, 1989.

Chelton, D.B., M.H. Freilich, and J.R. Johnson, Evaluation of unambiguous vector winds from Seasat scatterometer, J. Atmos. Oceanogr. Tech., vol 6, 1024-1039, 1989.

Chelton, D.B., Geosat observations of the Southern Ocean, presented at the Jet Propulsion Laboratory, Planetology and Oceanography Division Seminar, 1990.

Chelton, D.B., Estimation of time-averaged chlorophyll concentration from irregularly spaced satellite observations, presented at the Eastern Pacific Oceanography Conference, 1990.

Chelton, D.B., M.G. Schlax, D.L. Witter and J.G. Richman: Geosat altimeter observations of the surface circulation of the Southern Ocean, J. Geophys. Res., vol 95, 17877-17903, 1990.

Chelton, D.B., and M.G. Schlax, Estimation of time-averaged chlorophyll concentration from irregularly spaced satellite observations, J. Geophys. Res. (in press) 1991.

Schlax, M.G., and D.B. Chelton, Frequency domain diagnostics for linear smoothers, J. Amer. Statistical Assoc. (submitted) 1991.

Ongoing projects involve the analysis of altimeter data over the Southern Ocean, analysis of scatterometer data from Seasat, analysis of SSM/I data to infer surface fluxes of heat and water vapor, and the statistical properties of irregularly sampled satellite data.

P. Michael Kosro

Flament, P., P.M. Kosro, and A. Huyer, Mesoscale variability off California as seen by the Geosat altimeter, Proceedings of IGARSS '89, 12th Canadian Symposium on Remote Sensing, Vol 2, 1063-1068, 1989.

Ongoing projects involve the comparison of AVHRR images with field data from various projects.

Murray Levine

James, C., M.D. Levine and P.T. Strub: A straightforward analysis of Geosat altimeter data: comparison with hydrography off the California coast, presented at the AGU Ocean Sciences meeting, 1990.

Ongoing work involves the examination of alternate methods of using altimeter data to derive velocity fields (avoiding fitting orbit

errors and forming averages).

Robert Miller

Miller, R.N., and M.A. Cane: A Kalman filter analysis of sea level height in the tropical Pacific, *J. Phys. Oceanogr.*, vol 19, 773-790, 1989.

Miller, R.N.: Tropical data assimilation experiments with simulated data: the impact of the TOGA-TAO array, *J. Geophys. Res.*, vol 95, 11461-11482, 1990.

Miller, R.N.: Advanced data assimilation techniques in strongly nonlinear current systems, in the Proceedings of the International Symposium on Assimilation of Observations in Meteorology and Oceanography, 1990.

Ongoing projects include methods of assimilating altimeter data directly into numerical models, using differences between cycles, to avoid forming long-term averages.

James Richman

Wroblewski, J.S., J.G. Richman, and G.R. Mellor, Optimal wind conditions for the survival of larval northern anchovy: a modeling investigation, *Fishery Bull.*, vol 87, 387-398, 1989.

Pelegri, J.L., and J.G. Richman, The role of inertial oscillations and turbulent mixing in the dynamics of coastal upwelling, *Coastal, Estuarine and Shelf Science*, (submitted), 1991.

Richman, J.G., Zonal propagation of the deep low frequency currents in the central Pacific Ocean, *Deep-Sea Res.*, (submitted), 1991.

Richman, J.G., Low frequency transport variations in Drake Passage, *Deep-Sea Res.*, (submitted), 1991.

Stanton, B.R., and J.G. Richman, Density driven currents and sea level adjustment off the West Coast, South Island, New Zealand, *Cont. Shelf Res.*, (submitted), 1991.

Ongoing work includes 3-D ecosystem modeling in eastern boundary currents and the analysis of altimeter data in the Tasman Sea and elsewhere.

P. Ted Strub

Strub, P.T., The atmospheric event associated with the spring transition in the coastal ocean, presented at the AGU Ocean Sciences Meeting, 1988.

Strub, P.T., and C. James, Atmospheric conditions during the spring and fall transitions in the coastal ocean off western North America, J. Geophys. Res., vol 93, 15561-15584, 1988.

Strub, P.T., Large-scale context for the CTZ experiments, presented at the AGU Fall Conference, 1988.

Strub, P.T., C. James, A.C. Thomas and M.R. Abbott, Seasonal and non-seasonal variability of satellite-derived surface pigment concentration in the California Current, J. Geophys. Res., vol 95, 11501-11530, 1990.

Strub, P.T., C. James, and A.C. Thomas, The seasonal cycle of CZCS-derived surface pigment concentration in the California Current, presented at the AGU Ocean Sciences Meeting, 1990.

Strub, P.T., and CTZ Collaborators, The nature of the cold filaments in the California Current -- squirts or meanders? presented at the AGU Ocean Sciences Meeting, 1990.

Strub, P.T., Interannual variability of satellite-derived surface pigment concentration in the California Current, presented at the 24th Annual CMOS Congress, 1990.

Strub, P.T., Can we ground-truth altimeter velocities using coincident field data, presented at the Eastern Pacific Oceanographic Conference, 1990.

Strub, P.T., P.M. Kosro, A. Huyer and CTZ Collaborators, The nature of the cold filaments in the California Current System, J. Geophys. Res., (accepted) 1991.

Ongoing projects involve analysis of AVHRR, CZCS and altimeter data in eastern boundary currents and a comparison between different eastern boundary currents.

Andrew Thomas

Thomas, A.C., and W.J. Emery, Relationships between near-surface plankton concentrations, hydrography and satellite measured sea surface temperature, J. Geophys. Res., vol 93, 15733-15748, 1988.

Thomas, A.C., and P.T. Strub, Large-scale changes in patterns of chlorophyll concentration during the spring transition along the North American West Coast, presented at the AGU Fall Conference, 1988.

Thomas, A.C., and P.T. Strub, Interannual variability in phytoplankton pigment distribution during the spring transition along the west coast of North America, J. Geophys. Res., vol 94, 18095-18118, 1989.

Thomas, A.C., and P.T. Strub, Seasonal and interannual variability

of phytoplankton pigment concentrations across a California Current frontal zone, presented at the AGU Ocean Sciences Meeting, 1990.

Thomas, A.C., and P.T. Strub, Seasonal and interannual variability of phytoplankton pigment concentrations across a California Current System frontal zone, J. Geophys. Res., vol 95, 13023-13042, 1990.